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Chemical Classification of Space Debris

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Abstract Space debris, here referring to all non-operating orbital objects, has steadily increased in number so that it has become a potential barrier to the exploration of space. The ever-increasing number of space debris pieces in space has created an increasingly threatening hazard to all on-the-orbit spacecraft, and all future space exploration activities have to be designed and operated with respect to the increasing threat posed by space debris. Generally, space debris is classified as large, medium and small debris pieces based on their sizes. The large debris piece is easily catalogued, but medium to small debris pieces are very difficult to track and also quite different in damage mechanisms from the large ones. In this paper, a scheme of chemical classification of space debris is developed. In our scheme, the first-order classification is employed to divide space debris into two groups: natural micrometeoroids and artificial space debris. The second-order classification is based on their chemical patterns and compositions. The natural micrometeoroids are further divided into three types, namely mafic, metal and phyllosilicate micrometeorites, while the artificial space debris is divided into seven types, which are polymers, non-metal debris, metals and their alloys, oxides, sulphides and their analogs, halides and carbides. Of the latter seven types, some can also be further divided into several sub-types. Chemical classification of space debris is very useful for the study of the chemical damage mechanism of small debris pieces, and also is of great significance in constraining the origin and source of space debris and assessing their impact on spacecraft and human space activities.

Key words: space debris, chemical classification, space environment

1 Introduction

Space debris (or called orbit debris), which is potential to cause damage to spacecraft and space activities, refers to all non-operating orbit objects (Graham et al., 1999; Li et al., 2002). Because the damage to spacecraft by space debris is generally attributed to massive kinetic energy of particles, which is directly related to mass (size) and velocity, the grain size is consequently used as a main parameter for space debris classification. Space debris larger than 10 centimeters is classified as large debris, that between 10 centimeters and 1 millimeter as medium debris and that smaller than 1 millimeter as small debris (Graham et al., 1999; Li et al., 2002). In general, space debris of a given size varies in number with size. With increasing grain size, spatial density of particles tends to decrease.

Up to now, only larger debris (10 cm and bigger) could be catalogued. The number of smaller orbital particles (medium and small debris, less than 10 centimeters in size) is much greater than that of the large debris, and the number is continuously increasing (Li et al., 2002). In the prefigured future, small debris is very difficult to track.

Small orbit particles out of surveillance will be a main menace to spacecraft and human space activities.

There is a possibility that small space debris is quite different in damage mechanisms from large debris. A big particle can shatter a spacecraft due to its huge kinetic energy, whereas when small debris impacts the spacecraft the particle will penetrate the shield and the kinetic energy will be converted to thermal and chemical energy, which would make shield material and debris matter fuse, vapor, structurally transform and chemically change (Li et al., 2002). To some extent, these consequential changes will be fatal damage to spacecraft. At least they will cause part invalidation in function. Therefore, reliable scientific classification of space debris is very important to identify the origin and source of space debris and to assess their impact on spacecraft and human space activities (Graham et al., 1997; Warren et al., 1997; Ouyang, 1988; Graham et al., 1999; Li et al., 2002; Hampton and Virginia, 2004). Chemical classification of space debris is very useful to study the chemical damage mechanism of small debris and, therefore, it is badly needed.

2 Chemical Classification of Space Debris

In this study, we have developed a scheme for chemical classification of space debris. In this scheme, the first-order classification is for dividing space debris into two groups: natural and artificial debris. The former refers to micrometeorites and the latter to man-made orbital debris (Warren et al., 1997; Ouyang, 1988; Graham et al., 1999; Li et al., 2002; Hampton and Viginia, 2004).

The natural debris (micrometeorites) refers to dusts, resulting from mutual collision among asteroids and solid particles from comets (Graham et al., 1997; Warren et al., 1997; Ouyang, 1988; Ma and He, 2001). It is considerably complicated in mineralogy and chemical composition, and has an average chemical composition of chondrites. Especially, micrometeorites obviously contain typical meteoritic minerals such as olivine, pyroxene, kamacite and taenite, which are rarely seen in man-made debris (Warren et al., 1997).

The second-order classification is based on chemical patterns of the natural debris. Theoretically, micrometeorites should have more chemical/mineral types. In recent studies, only the following types have been found (Warren et al., 1997):

2.1 Natural debris (micrometeorite)

2.1.1 Mafic micrometeorite: composed predominantly of olivines and pyroxenes

2.1.2 Metal micrometeorite: made up of iron sulphides, Fe-Ni sulphides and Fe-Ni alloys (kamacite and taenite)

2.1.3 Phyllosilicate micrometeorite: consisting of spinels and hydrous silicates

Artificial space debris is mainly from all parts of spacecraft/rockets, or rejectamenta of manned mission (Warren et al., 1997; Ouyang, 1988; Graham et al., 1999; Li et al., 2002; Hampton and Viginia, 2004). It should be composed of various elements. A piece of individually man-made debris is generally simple in chemical composition. Even if it consists of several elements, its elemental patterns differ obviously from those of the micrometeorites. Hence, the second- and third-order chemical classifications of artificial space debris are also based on elemental patterns and material types. According to the chemical analyses of the collected space debris samples, artificial debris can be sub-divided into the following types:

2.2 Artificial space debris

2.2.1 Polymers (organic compounds): made up of elements, namely light elements C, H, O, N and P. These debris

particles are dominantly from thermal-control materials overcoating spacecraft, heat pipe working fluids (for example ethane), paint thinner, various fiber glass, epoxy, electrical insulators, various sealants, adhesives, etc.

2.2.2 Non-metal debris: consisting of relatively simple non-metal elements

2.2.2.1 Silicon particles: composed mainly of silicon and a little amount of impurity, stemming from electronic parts, optics, solar cells, encapsulates, test discs, etc.

2.2.2.2 Carbon particles: graphite, mainly from optical material and spacecraft structure

2.2.3 Metals and their alloys: one and/or more metal elements

2.2.3.1 Iron and its alloys: consisting of iron and minor amounts of carbon, chrome and nickel, derived mainly from various rivets and spacecraft structure.

2.2.3.2 Aluminum and aluminum-magnesium alloy: the component elements are aluminum and minor magnesium, stemming from various rivets, washers, wires and structure of spacecraft.

2.2.3.3 Copper and its alloys: consisting of copper and minor amounts of beryllium, zinc and tin, commonly derived from electrical circuits, electrical parts, wires, laser optical substrate, coatings of quartz discs, etc.

2.2.3.4 Refractory and cauter-resistant metals: including chrome, nickel, molybdenum, tungsten, and their alloys (for example inconel), mainly from thermal-control coatings of spacecraft.

2.2.3.5 Noble metals: including gold, platinum, silver, iridium, osmium, niobium, tantalum, etc., mostly from electrical circuits, electronic parts, solar cells, optics, capacitors, etc.

2.2.3.6 Thermal conductor alloy: for example, Bi-In-Pb-Sn alloy

2.2.3.7 Metals used for detectors: including metal germanium, lithium, tantalum, niobium, barium, zirconium, cadmium, etc.

2.2.3.8 Other alloys: for example, Al-Ni-Co alloy

2.2.4 Oxides

2.2.4.1 Silicic oxide (silicate): composed of SiO_2 , derived from various quartz test discs, optical filters, detectors, mica, thermal-control glass, ceramics, glass cloth, solar cells, etc.

2.2.4.2 Alumina: composed of Al_2O_3 , from rocket fuse-burning remnants, optics (man-made sapphire used as UV windows) and coatings of some parts.

2.2.4.3 Titanic oxide: composed of TiO_2 , a main compound of white paint, which is used as the thermal-control material of spacecraft.

2.2.5 Sulphides and their analogs: including (Hg, Ge, Pb)

Te, ZnSe, PbS, GaAs, CdSe, PbSe, LiTeO₃, GeAs, etc., mostly from coatings of optics, infrared detectors, diodes, solar cells, etc.

2.2.6 Halides

2.2.6.1 Nuclear emulsion: including AgBr, AgCl and AgI

2.2.6.2 Optical parts: including LiF, CaF₂, PbF₂, Th (F, Br, I)₃, MgF₂, etc.

2.2.6.3 Crystal-growth salts: including NaCl, KCl, CaCl₂, etc., which are astronaut's rejectamenta, or aerosol and crystallization of sea-water adhesive to the surface of spacecraft.

2.2.7 Carbide: SiC is from the structure of spacecraft, and LiCF is a kind of component of solar cells.

3 Discussion and Comments

The space environment that surrounds the Earth is being increasingly polluted by space debris. Space debris includes natural micrometeorites and man-made orbital debris that is made up of objects like non-functioning payloads, used rocket bodies, lens covers, separation devices, insulation, and small pieces from on-orbit fragments. Space debris originating from human space activity potentially endangers functional spacecraft, even obstructs any spacecraft from entering the space. Currently, the space density of space debris is so high that spacecraft faces a very high risk of being impacted by orbital debris, and shielding processing against orbital debris should be taken into consideration. Since the beginning of space flight, the collision hazard on the Earth orbit has steadily increased as the number of artificial objects orbiting the Earth has grown. Although the current hazard of debris to most space activities is low, steady growth of the amount of debris threatens to make some valuable orbital regions become increasingly inhospitable to space operations in the next few decades, and pollution of space environment due to space debris is highly expected (Ouyang, 1988; Li et al., 2002).

Collision with orbital debris which has severely damaged or destroyed a spacecraft did happen although only sporadically. Collision with large debris (>10 cm) could lead to change of the position and/or orbit of spacecraft, and more violent impact would make spacecraft break up, even disaggregate completely. Collision with objects as small as a centimeter in diameter could damage or prove fatal to most spacecraft, depending on where the impact occurs. Impacts with much more numerous debris particles that are a millimeter or less in diameter can damage optics, degrade surface coatings, or even crack windows. Low-grade damage is probably very widespread

in the low Earth orbit (LEO), but much of it is undetected because most spacecraft would not return to the Earth for examination.

As for the large debris, direct impact on operating spacecraft must be utterly abstained. Elusion from the large debris is effective using the catalogue of space debris made by the SSN (US) and the SSS (Russia) (Humpton and Viginia, 2004). As for the small debris, shielding is a most effective method to protect operating spacecraft against damage by the vast majority of these predominant small particles, including developing new materials and new designs to provide better protection from the environment with less weight penalty.

Current techniques and instruments could measure, track and catalogue nearly all orbital debris larger than 10 cm (LEO) or 1m (GEO), and parts of medium debris (>1cm). The smaller debris (<1cm), due to small size and long distance, could not be effectually photographed and tracked. So, characterization of space debris population must be accomplished by sampling the debris flux at particular locations and times, and using these data as a basis for estimating the characteristics of the general population. The flux can be sampled either directly (with spacecraft surfaces that are struck by debris) or remotely (by using ground- or space-based radars or optical telescopes that record debris passing through their fields of view). Another effective method is to develop and improve debris models in order to describe the current and future debris environment characteristics (Miao et al., 2001; Walker et al., 2002). But in fact, these methods could not describe truly the characteristics of the debris population, especially the smaller debris. Based on the elemental composition and features of different types of space debris and their residues (Graham et al., 1997; Warren et al., 1997; Humpton and Viginia, 2004), we could identify their origins, sources and types, and then further know the distribution of different types of debris in the debris population. Combination of chemical classification with debris population characterization is very helpful to study the damage mechanisms of space debris to spacecraft and is also important to distinguish particles which are probably extraterrestrial in origin from those which are probably artificial debris as contaminants.

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